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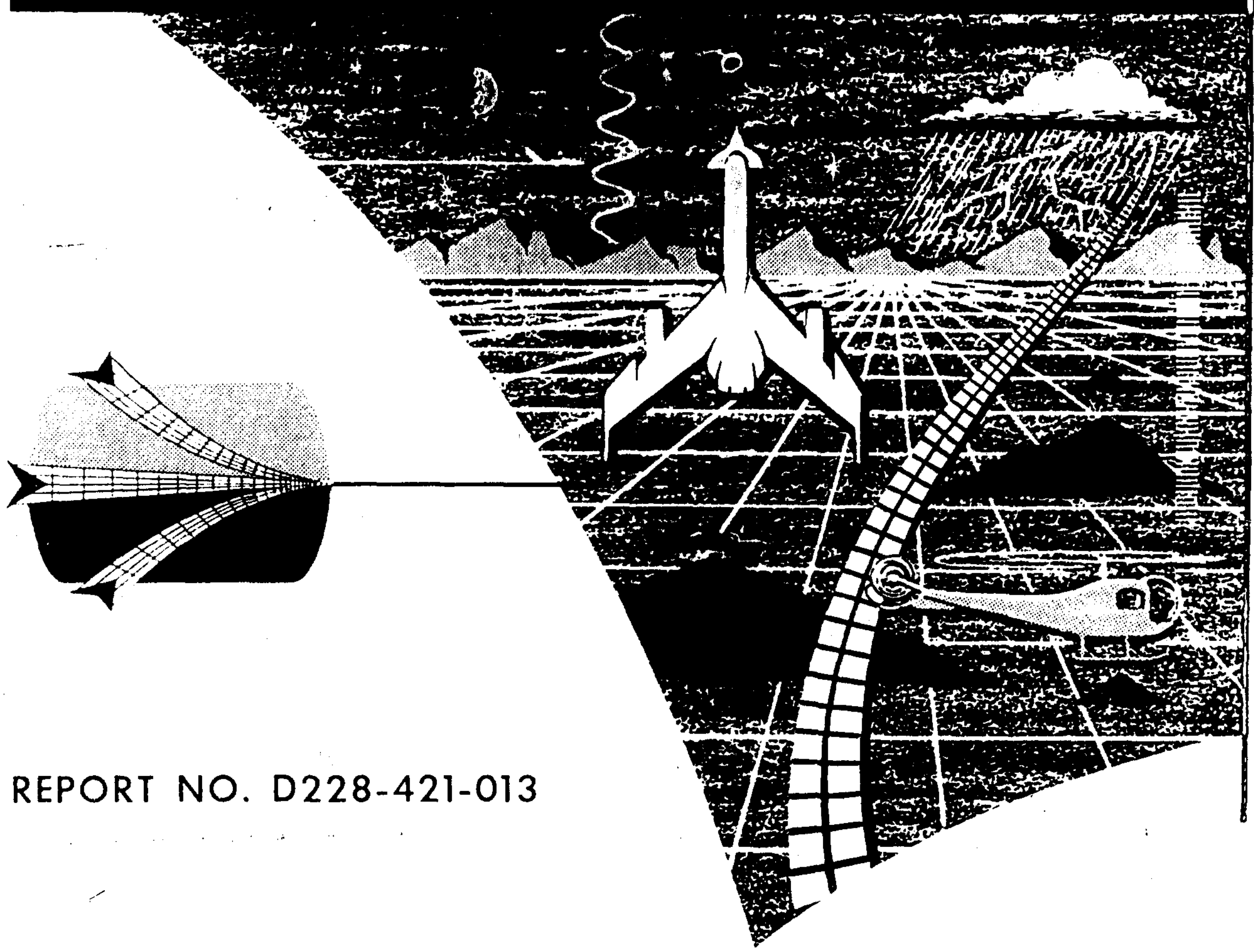
EFFECT OF STIMULUS AMBIGUITY IN THE DISPLAY OF ATTITUDE INFORMATION



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EFFECT OF STIMULUS AMBIGUITY IN THE DISPLAY OF ATTITUDE INFORMATION

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This report presents work which was performed under the Army-Navy Instrumentation Program, a research and development program directed by the United States Navy, Office of Naval Research. Special guidance is provided to the program from the Army Signal Corps, the Office of Naval Research and the Bureau of Naval Weapons through an organization known as the Joint Instrumentation Working Group. The group is currently composed of the following representatives:

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- Mr. L. O. Anderson

U. S. Navy, Bureau of Naval Weapons
- Cdr. J. Perry

U. S. Army, Office of the Chief Signal Officer
- Mr. W. C. Robinson

The paramount objective of ANIP is to simplify and to improve the relationships between man (the operator) and the machine he controls to provide the man-machine complex with all-visibility operating capabilities.

ABSTRACT

Within the Army-Navy Instrumentation Program a great deal of attention has been given to the development of a vertical display based upon the contact analog concept. The task which ANIP has set for itself is to electronically re-create the visual stimulus cues which are both necessary and sufficient for attitude control. It proposes nothing less than to create an artificial picture of the real world to which the pilot can react exactly as though he were on VFR.

This objective gives rise to numerous problems. One, which must be considered, is the position of the vertical display relative to the pilot's line of vision. It is common sense to suppose that the electronically generated display should be spatially superimposed over the terrain it represents. This follows from the fact that with displacement of the display a different set of stimulus-response elements will be required between IFR and VFR. It has been shown in a previous study (2) that lateral displacement of the vertical display disrupts performance.

There are, however, some very practical difficulties involved in placing the display directly in front of the pilot. Of first consideration is the fact that the display might interfere with VFR. This objection could be obviated with the development of a transparent display which will permit the simultaneous viewing of the terrain and the electronically contrived image.

It is not the purpose of this report to evaluate the feasibility of a transparent display from an engineering point of view, but rather to determine whether the presence of a grid line display superimposed over the terrain acts to degrade performance. Subjects were required to track in

two dimensions (roll and pitch) to a grid alone, to a picture of the real world alone, and to the grid superimposed over the real world picture. No evidence was obtained that the presence of the grid would interfere with VFR.

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INTRODUCTION

The Army-Navy Instrumentation Program has given considerable attention to the development and utilization of the contact analog display. This type of display is based upon the notion that instrument flying will be facilitated if the stimulus cues critical to visual contact can be electronically re-created in their original perceptual form. The approach is somewhat atheoretical since few assumptions or speculations are made concerning perceptual organization. Rather, the idea expressed (1, 3, 5) is that, since humans can fly quite capably when visual contact is available, it is then the task of the engineer to reproduce the necessary visual elements which are used in contact flying.

One characteristic of any perceived object (earth, sky, horizon, obstacles, etc.) is that it occupies space and is organized relative to the perceiver. Things are seen as being above, below, far, or near the observer's body. There is some indication (2) that these relationships must be preserved in the use of the contact analog display. Assuming this to be the case, it may be necessary for the vertical display (the one showing aircraft altitude) to be positioned directly in front of and at eye level to the pilot. If this arrangement is presented, however, it will interfere with normal vision unless the display is reflected from the surface of, or generated from within, a transparent medium. This would allow the pilot to view the outside world as well as its representative image.

A difficulty arises with such an arrangement. The electronically generated image will be superimposed over the terrain it represents, and often the pilot will be able to view both simultaneously. It is altogether

unlikely that an analog display would ever achieve a point for point correspondence with the terrain. This lack of correspondence gives rise to some ambiguity in the visual cues present. It is the intent of this study to determine whether this ambiguity will interfere with performance.

METHOD

Subjects

Sixteen college students served as Ss in this experiment. All were male having been acquired from a roster of the Reserve Officers Training Corps of Texas Christian University. They were naive with respect to both flight training and psychomotor testing. All Ss were volunteers and were paid for their participation.

Apparatus

The Ss were tested within an 80 x 40 x 48 in. plywood enclosure. Within this compartment a pilot seat and an aircraft control stick assembly were located. In one wall of the enclosure an 18 x 15 in. opening had been cut. A 30 x 24 in. vertically mounted translucent screen was recessed 9 in. behind the opening. The pilot seat faced the opening and the recessed screen. The control stick, located in front of the pilot seat, was pivoted at floor level.

A Besler Vu-Graph projector situated outside the enclosure was used to cast pictures on the translucent screen. Since the screen was at eye level to the seated subject, the pictures could be seen (somewhat as though projected at infinity) through the rectangular opening in the wall of the enclosure.

The transparency holder in the projector, being servo driven by an analog computer (Donner, Model 3300) could move in two degrees of freedom. It could rotate about a line drawn perpendicularly to the surface of the film. This caused the projected image to rotate also. Since the transparencies were panoramic (showing a great deal of the sky, terrain, horizon, etc.), the effect was altogether similar to the view experienced by a pilot through the windshield of his aircraft during a roll maneuver.

The other movement produced a vertical displacement of the projected image on the screen, thereby creating the illusion of a change in pitch attitude. As a descriptive convenience these movements, along with their associated controls, errors, etc., will be referred to as roll and pitch in the remainder of this report.

The S could control movement of the display, which was to be interpreted as his attitude, by means of the control stick. Lateral displacement of the stick produced roll (i.e., it caused the display to rotate) while fore-and-aft displacement gave occasion to pitch.

The relationship of control stick movement to the corresponding display movement was similar to the relationship obtained in a conventional aircraft. A leftward lateral displacement of the stick would give rise to a clockwise rotation of the horizon, while the opposing movement would generate a counter-clockwise rotation of the image. Similarly, when the control stick was displaced toward the back, the picture would undergo a downward translation. Pushing the stick away from the body produced an upward movement of the photographic image.

In each control channel (pitch and roll), the computer acted upon two signals. The rate of displacement was determined by the position of the control stick (rate being in linear relationship to the stick position as calculated from the center or null position) and a disturbance source. This latter input was generated by means of a motor driven cam which rotated at 1 rpm. The apparent disturbance, as displayed on the screen, was similar to the effect experienced in a helicopter under turbulent weather conditions.

A control delay was inserted between subject input and computer output. These lags were in both control channels and approximated the delays

obtained in the control of a helicopter for each of the control parameters.

It is possible that two psychomotor tasks could differ in difficulty yet produce equivalent performances. This could occur if the S set his own standard for success and expended only enough effort to achieve that standard. In this case, however, the amount of work done would differ between the two tasks. For this reason, an indication of S output was required. The index chosen was admittedly gross, but probably adequate in view of the results of the experiment. Measurement of S output was obtained by counting the frequency of control movements which exceeded a particular accelerative value. Any lateral displacement of the control stick having a second order derivative (as measured at the grip) in excess of 9 in./sec^2 was enregistered for the roll channel. Any fore-and-aft movement of equivalent accelerative value was counted for the pitch channel. These movements were identified by measuring the rate of change in voltage on the control stick potentiometers. The frequencies of these movements were continuously enregistered on automatic counters.

The equipment (control stick computer, servo driven projector, etc.) is more fully described in another report of this series (4).

The stimuli (pictures projected on the translucent screen) consisted of (1) a grid line display having converging perspective lines as shown in Figure 1, and (2) three kodachrome transparencies (S_1, S_2, and S_3) of open terrain. By way of illustration S_1 is shown monochromatically in the same figure.

The characteristics of the grid (G) were selected as being representative of the type of display that could be electronically generated. The kodachrome transparencies were obtained of the rolling hills surrounding the Fort Worth area and were fairly representative of the view a pilot

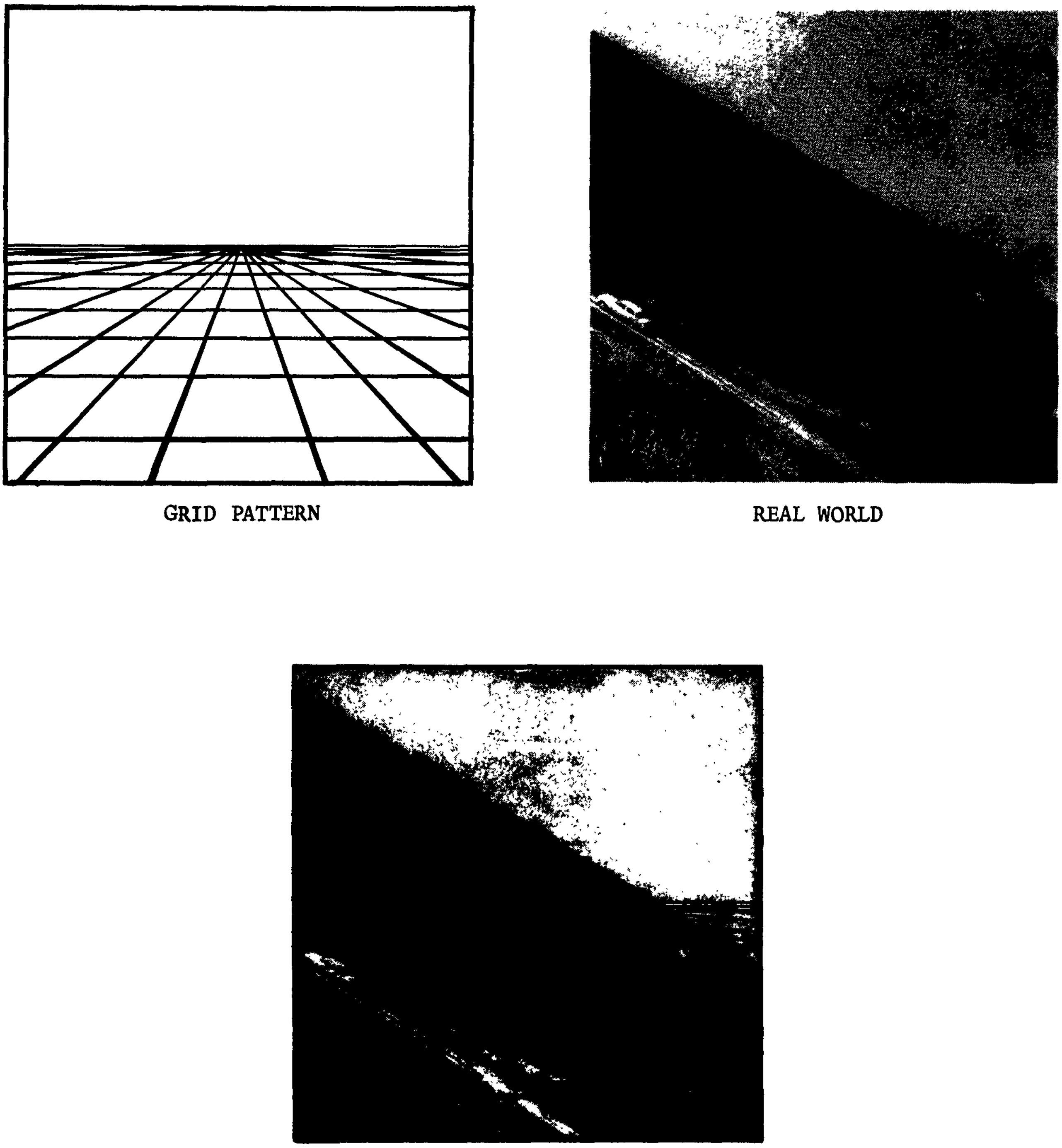

Figure 1.

would obtain at low level under conditions of visual contact. In all cases the scenes displayed rather uneven skylines. This made the identification of the absolute horizon (the horizontal and zero azimuth a difficult task for the Ss to perform when these pictures were presented.

Error scores (momentary error integrated through time) were recorded for both pitch and roll. These scores were based upon absolute error (/e/) and were accumulated irrespective of direction or sign. Thus, in roll, a clockwise error of a given magnitude produced a positive error equivalent to that produced by a counter-clockwise error of the same magnitude. Similarly, in pitch, "up" errors were accumulated with "down" errors. In both channels momentary error was proportional to the degree (in roll) or distance (in pitch) from the straight and level visual condition.

We may say, for example, that in roll

$$/e/_R = \quad (S_R - M.P.)$$

where S_R - null position for roll

M.P. - momentary position

and that in pitch

$$/e/_P = \quad (S_P - M.P.).$$

This is to say the integrated absolute error is equal to the accumulated momentary difference between display position and the null position for the channel affected.

These error scores were continuously enregistered on single pen Sanborn recorders (Model 151).

Procedure

Prior to testing, each S was instructed in the procedures and purposes

of the study. These instructions are reproduced as Appendix A. The typical procedure consisted of seating S in the enclosure, projecting a picture on the screen, and activating the computer. The relationship of control movement to display movement was demonstrated. In substance the instructions to the S were to hold the picture centered and level. Actually, however, the S was admonished to "fly" level. He was, for example, told to "bring your left wing up" when the picture rotated counter-clockwise or to "put your nose down" when the pictured horizon drifted downward. All references to position and motion were as though the S moved and the picture remained fixed.

After five minutes of training, test procedures were initiated. The S received no aid during testing nor was his performance remarked upon or evaluated by the experimenter.

Basically three displays were involved during the test procedures. These were: (1) the grid line display (G) alone, (2) each of three transparencies of the real world (A, B, and C) alone, and (3) the grid line display in certain superimposed combinations with the real world transparencies (G + A, G + B, and G + C).

Except for the order of stimulus presentation, all Ss were treated similarly. Each was given 81 tracking sessions of two minutes duration each. Twenty-seven of these were with G, nine were with A, nine with B, nine with C, nine with G superimposed upon A (G + A), nine were with G + B, and finally, nine were with G + C. The order of presentation for the 16 Ss was randomized. On those trials where the stimuli were superimposed (so that the S saw both grid and real world picture), the horizon as depicted by the grid, usually varied from the true horizon (as known from the photographic data) shown on the transparency. These variations are shown

in Table I for G + A.

TABLE I

Position of the Grid Line Horizon to the Transparency. A Horizon for the Nine G + A Combinations.

Variation	Pitch	Roll
1	0^{o}	0^{o}
2	0^{o}	20^{o} clockwise
3	0^{o}	20^{o} C-clockwise
4	15^{o} up	0^{o}
5	15^{o} up	20^{o} clockwise
6	15^{o} up	20^{o} C-clockwise
7	15^{o} down	0^{o}
8	15^{o} down	20^{o} clockwise
9	15^{o} down	20^{o} C-clockwise

Only in the case of Variation 1 was there concurrence in both pitch and roll between the depicted horizons. Thus, with the remaining stimulus variations of the G + A combination, Ss were given inconsistent cues with reference to the position of the horizon.

The variance between cues which have been described for G + A also existed for the G + B and G + C combinations.

When the combined stimuli (G + A, G + B, and G + C) were given, the Ss were instructed to "ignore the grid and fly straight and level" with respect to the real world picture. The entire purpose of the study was to determine whether the Ss could successfully ignore the grid or whether its presence contributed to error. It was suspected that simultaneously learning to fly the grid along might interfere with the combinational

presentation. If error was produced by the inclusion of the grid (A compared to G + A, B compared to G + B, and C compared to G + C), the utility of a transparent vertical display would be questionable. This would follow from the fact that any electronically driven display will differ considerably in its geometry and the rate of movement of its sections from the untransformed visual image of the real world being depicted. Often it would be necessary for a pilot to alternate rapidly between the electronic display and contact vision. With the former superimposed over the latter, the tendency will be toward perceptual fusion of the two displays. Since the basic geometries will vary somewhat, this difference could be a source of irritation and confusion to the pilot. It is important that the pilot select between cues (visual contacts would doubtlessly be preferred) when both are simultaneously present.

RESULTS

In this study measurement was made of four dependent variables. These were (1) the absolute error in the pitch channel ($/e/_p$), (2) the absolute error in the roll channel ($/e/_R$), (3) the frequency of control movements in pitch having second order derivatives in excess of 9 in./sec^2 (A_p), and (4) the frequency of control movements in roll having second order derivatives of an equivalent magnitude (A_R).

For purposes of tabulation and analysis it was convenient to exercise transformations upon the obtained scores. It was, for example, discovered that A_p and A_R were not normally distributed. This fact is pre-emptive to the use of statistical analysis using techniques based upon normal distribution parameters. It was determined, however, that these scores could be normalized by the use of a log transformation. This was accomplished, as

can be witnessed in Table II.

TABLE II

Means for the Three Displays Under the Four Conditions of Measurement.

MEASUREMENT	GRID	REAL WORLD	REAL WORLD AND GRID	t*
Absolute Error in pitch $/e/_p$	156	188	184	N.S.
Absolute Error in Roll $/e/_R$	104	122	126	N.S.
Index of Efficiency in Pitch E_p	.0021	.0017	.0016	N.S.
Index of Efficiency in Roll E_R	.0027	.0023	.0023	N.S.

* These t scores are based upon the differences between the real world displays and the superimposed stimulus displays only. The differences based upon the grid alone were not evaluated.

It was also surmised that the presentation of the means for log A_p and log A_R would not be particularly meaningful unless the error scores happened to be equal, which was, of course, not the case. Since these scores could assume significance only within the context of performance, it was decided that the data be presented in the form of efficiency indices. The concept of efficiency involves both input and output being

the ratio of performance to effort expended. Since log A_p and log A_R are indicative of effort, it was necessary to convert the error scores ($/e/_p$) and ($/e/_R$) into performance indices. This was performed by taking the reciprocals at these values ($\frac{1}{/e/}$).

Efficiency could then be described by the formula

$$E = \frac{\frac{1}{/e/}}{\log A}.$$

The means, based upon the transformations described above, are presented in Table II. It may be seen in Table II that no distinction is made between the results using the three real world transparencies (A, B, and C) or between the results of the twenty-nine stimulus combinations (3 transparencies x 9 positional variations of the grid) of the superimposed presentations. The data are presented in this manner because it was evident that the differences obtained were without statistical significance. The means within each cell of Table II are consequently based upon 432 (16 Ss x 27 repetitions) observations.

For all measurements and control parameters, the grid along (G) is superior to either the real world along or combined with the grid. This result, although not unexpected, is irrelevant to the hypothesis being tested. The critical comparison of this study is between the real world and the combinational stimuli. Here we find the differences inconsequential.

DISCUSSION

It is evident that with the irregularities which are characteristic of the earth's terrain, there will be a considerable geometrical variation between an electronically driven display of the terrain and the terrain as interpreted by the unaided eye. This will become particularly evident if a transparent vertical display is used which superimposes one image upon the other.

It was the purpose of this study to determine whether this variance in cues would prove disruptive to performance. On the basis of the results of the present experiment, there is no evidence to confirm this hypothesis. The presence of the anomalous cue (the grid) did not interfere with performance on the superimposed stimulus problem.

Recognition should be given, however, to the limitations of the present experimental design. Although simulation was made of some of the differences that will exist between the real world vision and an electronically driven display, it should be appreciated that if a transparent vertical display is produced, the variances between it and unaided vision will be more abundant and exceedingly more complex than were those selected for study in this experiment.

The results of this study should be interpreted with care. They are negative in that they uncover no problem relative to the use of the vertical transparent display. Problems may exist, however, which were not discerned by the methods employed in this experiment.

SUMMARY

The hypothesis investigated was that through the utilization of a vertical transparent display of aircraft attitude, the inherent differences

of spatial geometry and terrain organization between contact vision and the electronic image would prove a detriment to performance.

Sixteen ROTC students controlled a display in pitch and roll under the simulated conditions of (1) grid alone, (2) contact vision, and (3) contact vision with the grid superimposed in various aberrant positions. The presence of the grid in the third condition did not interfere with performance. The hypothesis was not confirmed.

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APPENDIX A

Instructions to Subjects

You are going to participate in an experiment which has been designed to help us understand some of the problems of flight instrumentation. Be seated and imagine yourself to be flying an airplane. You can see the terrain through the window in front of you. With this control stick you can control the attitude of your plane. As you can see, when the stick is pulled back the nose of the airplane goes up. When the stick is pushed forward the nose goes down. When you push the stick to the left, the left wing goes down, and when you push it to the right, the right wing goes down. It is your task to fly straight and level at all times. Try to fly toward the horizon with your wings held level. Sometimes it will be difficult for you to know exactly where the horizon is but do your best.

On some trials you will see a natural terrain. On other trials you will only see a grid line display. (Show grid). On still other trials you will see the natural terrain with the grid line display superimposed over it. (Show the superimposed combination). Whenever the natural terrain is shown alone or when it is combined with the grid, fly the horizon based upon the natural terrain. In other words, ignore the grid when it is combined with the natural terrain. When the grid is shown alone you must, of course, fly level to it.

Before testing I am going to give you some practice flying to each of the situations I have shown you. Do you have any questions?

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